Engineering Case Library

ECL 109

Development of a High Speed Weighing Machine at FMC

I. Introduction

When Mr. Phil Bunnelle came to work for FMC Corporation, its Central Engineering Lab was developing electronic, high speed weighing equipment for use in the packaging industry. One machine FMC had already built determined the number of rolls of life-savers in a carton and rejected cartons not containing the correct number. Phil's first job was to develop a bread weighing machine. The purpose of the machine was to save bakers money by reducing "give-away" while at the same time preventing the production of underweight loaves. The machine was to reject and recycle loaves of dough which were overweight or underweight and add balls (increments) of dough to the slightly underweight loaves to bring them up to weight. The bread weigher was also to generate a signal, representing average loaf weight, which would control the machine dividing the raw dough into loaves.

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In the packaging of consumer products such as food some states require that no package have a net weight less than the labelled weight, while others may allow a small percentage of be underweight. In any case, the manufacturer has to "scale" heavy, i.e., set the average weight above the minimum allowed in order to assure that the normal scatter or weight spread from his filling machine does not cause him to produce some underweight packages. The worse the scatter the higher he must scale in order to stay above the minimum, and the more product he "gives away". In highly competitive industries the amount of "give-away" may have a very significant effect on profit. To reduce "give-away" many manufacturers have gone to the use of high speed "check weighers" following the filling operation, which will reject any underweight packages; thus they can scale lighter without fear of producing underweight products. Some "check weighers" also generate a feed back control signal to regulate the average weight produced by the filling machine, as was the case with the bread weight controller.

On most FMC high speed weighers, a converyor belt brings the product onto the scale head, which is pre-loaded by a spring to within a few grams of the expected weight (see Fig. 1). The scale then measures the difference between what

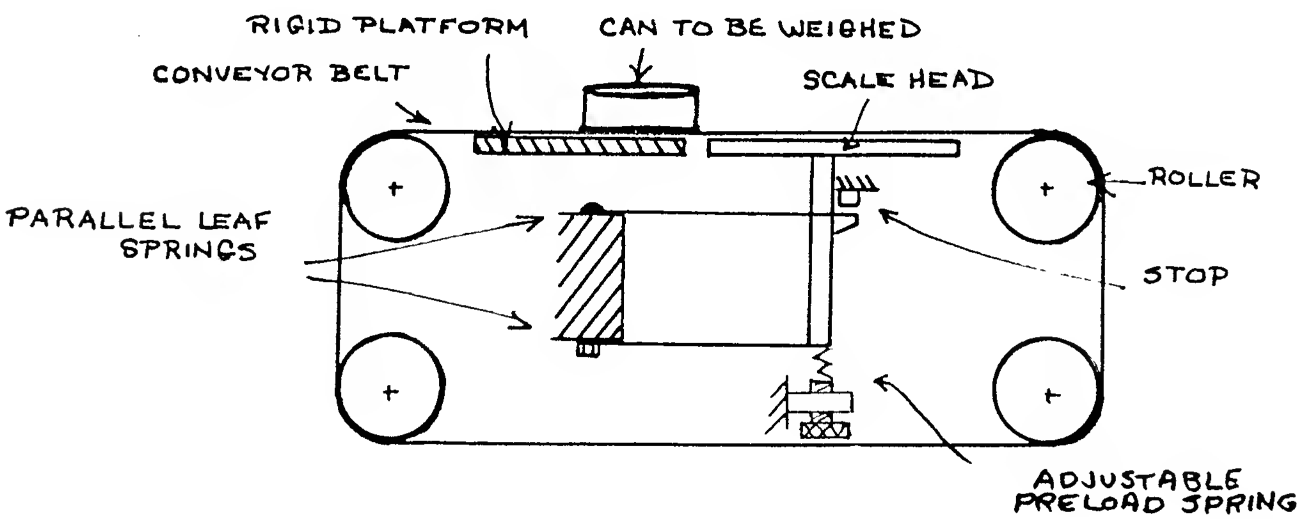


Figure 1
Scale Head with Pre-Load Springs

the product should weigh and what it actually weighs. This differential weighing technique provides better sensitivity than measuring total package weight. The weigher measures peak scale head deflection. This is a faster process than waiting for the spring-loaded scale head to reach a steady-state position before measuring deflection, and also provides better sensitivity.

As a package leaves the scale head, a logic circuit "remembers" its weight. A sensor detects the presence of the package as it moves along the belt and activates a reject mechanism if the logic "remembers" that the package weighs too little. On some FMC weighers, the sensor also sets the memory to zero in preparation for the next package. FMC's simplest weighing machines merely reject underweight packages. To accomplish rejection most FMC machines have a gate which swings across the conveyor belt, forcing the package down a side belt. There are also other rejection methods. The typical FMC machine can weigh five packages per second. Typical scale head deflection is about .012 - .015 inches. About .1 second elapses from the beginning of weighing to peak scale head deflection. (See Fig. 2).

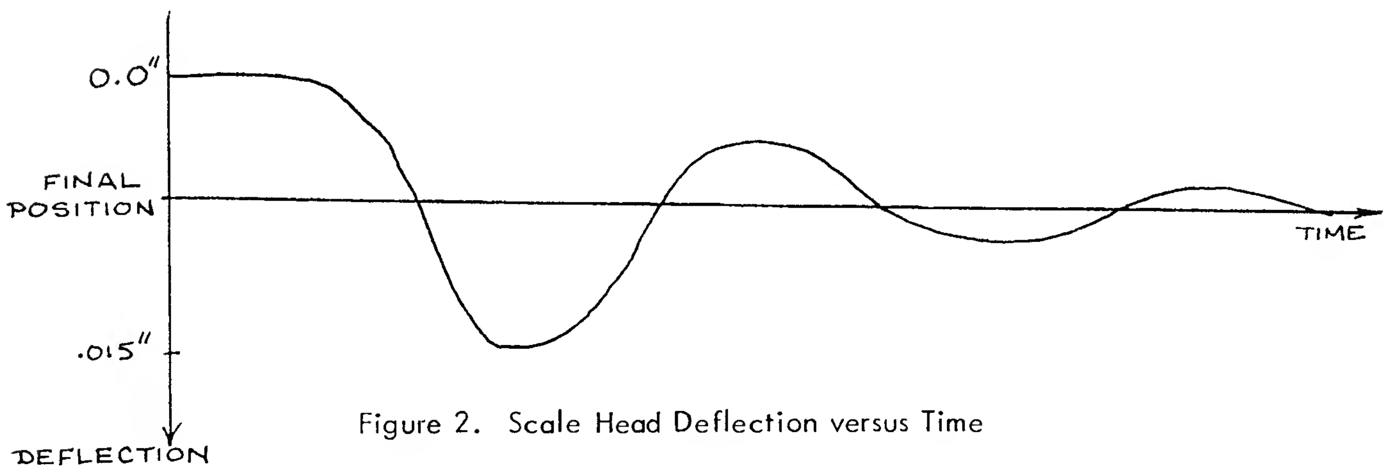


Figure 2. Scale Head Deflection versus Time

Before Phil came to work for FMC in 1957, he had spent three years as a college lecturer and three years at John Deere, a large mid-western farm machinery manufacturer. Phil received his B.S. in mechanical engineering in 1949 and his M.S. in agricultural engineering a year later.

FMC was one of the first "conglomerate" corporations. A California manufacturer of canning and cooking equipment merged with a manufacturer of orchard spraying equipment to form Food Machinery Corporation in 1928. The company thrived with the growing California fruit and vegetable industry and now has several national and international branches which altogether employ about 50,000 people. The company owns divisions which manufacture pumps, oil field equipment, chemicals, and even barges and amphibians in addition to packaging machines and ground handling equipment for airlines. With increased diversification, the name was changed to FMC Corporation.

The Central Engineering Lab which Phil joined developes new FMC products. In addition, the Lab accepts outside contracts from time to time and helps other FMC divisions with unusual problems and overload work.

II. Initial Development of the Fluidic Weigher

Paul Seaborn, Phil Bunnelle's office mate at FMC, had participated in the design of the machine which counted life saver packages. He also worked on the bread weight controller. Later, Paul and other engineers began developing a new, multi-purpose machine which would perform a number of weighing and rejecting functions. They wanted to develop a single instrument which would satisfy the needs of many customers. Unfortunately, the customer's individual requirements were quite stringent and sometimes conflicting. Phil often heard Paul and the field service men discussing the problems they had with the machine. Phil himself was spending three days a week at the Langendorf Bakery in San Francisco trying to get the bread weigher to operate properly. "The wiring looked life a rat's nest", Phil commented. The machine's complicated electronics were a particular disadvantage because the men who were to service the machine in the field had primarily mechanical training. Another difficulty was that the bread weigher was somewhat inaccurate and unreliable. Gas-filled tubes known as thyratrons were used in classification of the bread weights. The biasing on the

thyratrons tended to drift, causing incorrect classification of the dough. Downstream, the machine would add the wrong sized ball of dough to the dough on the conveyor belt. "There must be a better way to make an accurate high speed weighing machine", Phil often thought to himself.

In 1960, soon after FMC had its bread weighing machines installed in the field, the Harry Diamond Ordnance Lab in Washington, D.C. announced that it had developed some fluidic devices. Upon reading descriptions of these devices in trade journals, Phil realized that they had precisely the high speed and sensitivity characteristics suitable for the FMC weighing machines. Unfortunately, no fluidic devices were commercially available at that time. Phil even mentioned the possibility of using fluidic devices to his supervisors. They were not enthusiastic about the idea. Nevertheless, Phil kept the idea in the back of his mind.

Two or three years later, Corning Glass Co. began to sell some simple fluidic components. Phil bought several of these and began totinker with them. Phil had recently been doing some independent research and suggested using fluidics to his supervisors again. This time they were more receptive to the idea and put Phil in charge of a project to see how fluidic devices could be applied to the FMC product line.

Phil had two basic types of fluidic devices to experiment with: a "turbulence amplifier" and a "wall attachment" device. A turbulence amplifier consists of a fluid laminar flow jet which passes through a chamber. The flow can be made turbulent by a control jet of fluid entering the chamber from the side. Some turbulence amplifiers have several control jets. If the laminar flow becomes turbulent, very little pressure is recovered at the output side of the chamber. Thus, the "turbulence amplifier" is an on-off device controlled by jets entering the chamber from the side. The device is an amplifier in the sense that a small control jet can govern the flow of a large supply jet. Logically a turbulence amplifier having more than one control

jet behaves as a NOR gate. That is, the device is on (allows the laminar flow jet to pass through it) if neither A nor B nor C nor D (refer to Fig. 3) has a fluid passing through it which would interrupt the laminar flow jet. When the jet is not interrupted, about 30% of the pressure is recovered at the output. If the stream becomes turbulent, almost no pressure is recovered. The device stays off until the disturbing stream is removed.

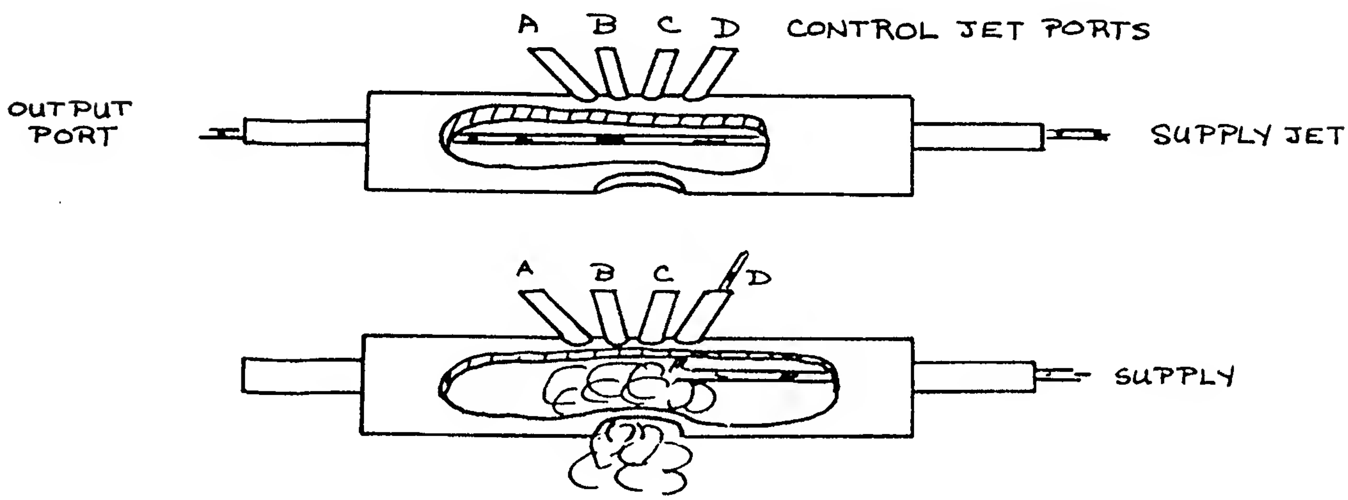


Figure 3. Turbulence Amplifier

A "wall attachment" device behaves as a flip-flop. It consists of a power jet which latches into one of two channels. The power jet may be switched to the other channel by a pulse entering from the appropriate side. The fluid enters at I (refer to Fig. 4), latches into 0_1 or 0_2. If it latches into 0_1, a small pulse (relative to the main stream) from A will switch the flow into 0_2, where it will remain until a pulse from B switches the stream back into 0_1. If two or more control channels are used on the same side and the power jet is properly biased, the wall attachment device has the logical function of an OR gate, or a NOR gate, depending on which output channel is considered.

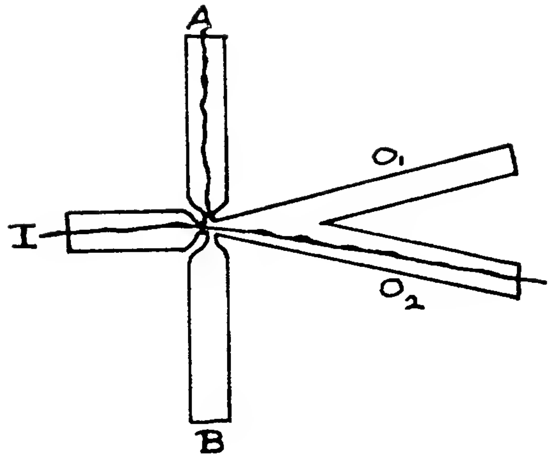
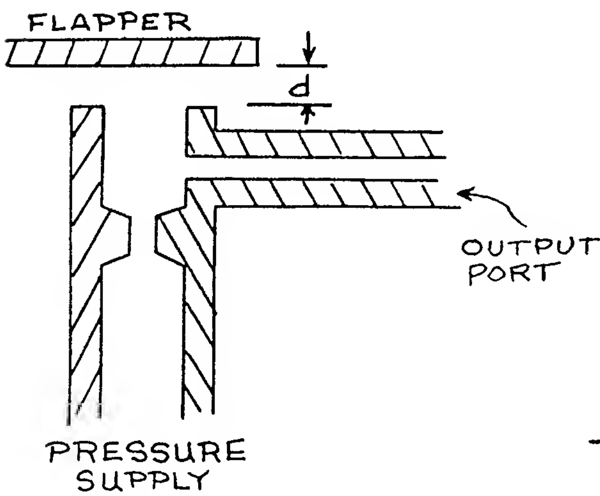
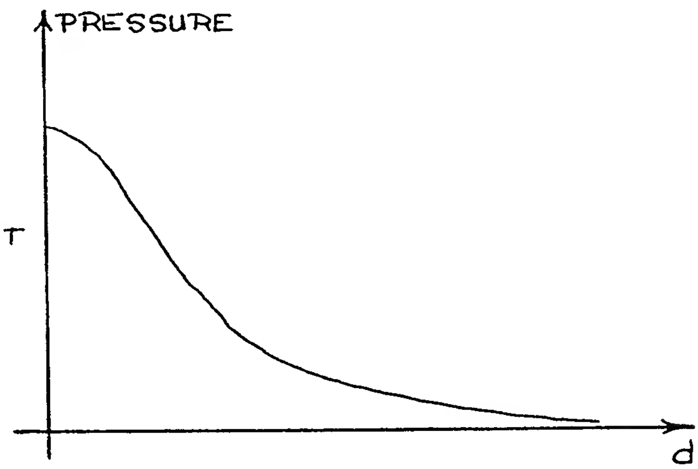


Figure 4. Wall Attachment Device

Phil also experimented with a "back pressure" or "flapper nozzle" valve, which consists of a nozzle connected to a pressure supply through a constriction. Rather than performing a logic function, this valve acts as an input or sensing device to a fluidic circuit. Fig. 5(a) shows the valve and Fig. 5(b) shows the pressure developed at the output port of the device as a function of d, the distance of the flapper from the mouth of the device.



a. Flapper Nozzle Valve



b. Output Port Pressure versus Flapper Distance

Figure 5

Phil decided to try using fluidic devices in a simple application first -- a can weigher which detected and rejected underweight cans. This weigher was called a "slide weigher" because cans slid down a ramp onto the scale head rather than being moved onto it by a conveyor belt. The scale head itself was also tilted. Phil outlined for himself the functions which he wanted the machine to perform. He hoped to devise ways of performing all these functions fluidically so that there would be no fluidic-electrical interfaces within the machine. The machine's functions were as follows:

1. It had to detect the scale head position. Several ways to do this occurred to Phil. He hoped that he could use the hardware from the existing machine and that he would be able to make the change to fluidics by replacing the electronic logic with fluidic circuit. He intended to use the original machine housing and the same scale head mechanism. However, he needed to have a fluidic input to his logic circuit. To detect scale head position, Phil decided to attach a blade under the scale head and to position a turbulence amplifier beneath the blade. Underweight cans would not produce deflections large enough to cause the blade to interrupt the jet (see Fig. 6). This arrangement would provide the input information as to whether the package on the scale head was underweight. The technique could be expanded to include more turbulence amplifiers for the purpose of classifying weights into several categories.

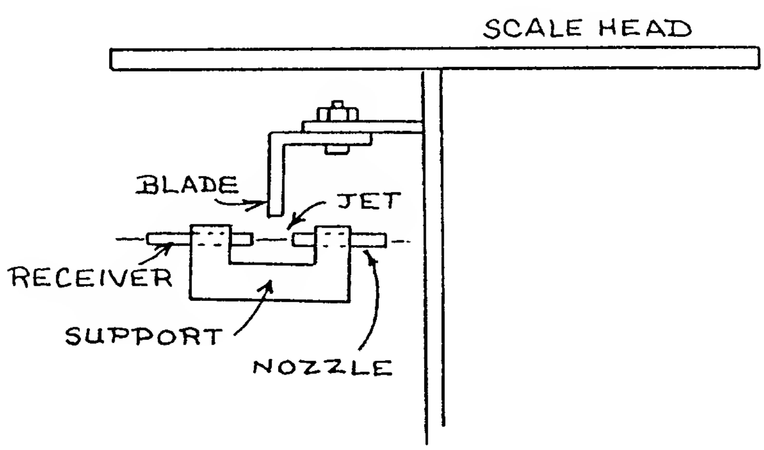


Figure 6. Scale Head Position Detection

2. The machine had to remember whether or not a package just weighed was satisfactory. If the package was good, the machine needed to remember this until the package had passed the reject mechanism. If a package was unsatisfactory, the machine needed to remember this until it rejected the can.
3. The machine had to sense the position of the package in order to trigger the reject mechanism at the proper time -- if a reject was necessary. Position sensing could be accomplished in many ways. In an electrical system, for example, can position could be sensed by a metal detector or by a photo cell. Phil wanted to develop a way to detect package position fluidically.
4. The machine had to reject unsatisfactory packages. The slide weigher which Phil had decided to work with had to remove underweight cans as they slid off the scale head.
5. The machine had to reset its memory in preparation for storing information about other packages. The machine could process packages faster if it could store information about more than one package at a time. Then the memory capacity would not delay the check-weighing process. If the memory could contain information about only one package at a time, a new package could not be weighed until the previous one had already passed the reject mechanism.

Phil gave considerable thought to the transformation from electronic devices to fluidic ones and finally devised an all-fluidic weighing machine which used twelve fluidic devices. He even invented and made his own fluidic devices for detecting can presence and rejecting underweight cans (see Appendix, which includes the five device circuit Phil later developed). The fluidic system worked beautifully at night but during the day when he tried to demonstrate it to others Phil reported that the weigher performed miserably. "You know how they always say that things work well when you're by yourself but that in front of others, if anything can go wrong it will. Well, it was certainly true in my case, and I was getting fairly

paranoid", Phil commented. Finally, Phil discovered that his daytime problems were caused by people opening and closing the door as they went in and out of the lab. The door movement was perturbing the air in the room which in turn was causing an exposed laminar flow jet to become turbulent. Phil remedied this situation by placing his apparatus in a box to shield it from air currents. Then his fluidic weighing machine worked well. Soon after that, Phil demonstrated his work to his supervisors and proved to their satisfaction that use of fluidic devices was certainly possible and perhaps practical.

III. Attempts to Improve the Performance of the Fluidic Weighing Machine

Phil's idea of replacing the electronic logic in the weigher with fluidic logic resulted in a scheme which had no significant advantages over the original electronic circuit. "The fluidic weigher was a standoff with the electronic weigher as far as cost and performance were concerned", Phil recalled. The fluidic devices he had used were much more reliable than the thyratrons in the original electronic weigher. However, other engineers at FMC had replaced the thyratrons with reed magnetic switches. The switches did not have biasing that drifted, and their use improved the reliability of the electronic weigher considerably, and also reduced cost. In fact, the performance of the improved electronic weigher was as good as the performance of the new fluidic weigher.

The new weigher had some disadvantages which the electronic one did not have. One concern to the FMC management was that contaminated air supplies at customers' installations might ruin the fluidic devices in the machine. Unless filtration of the air supply was very good, bits of dust and grit or droplets or oil or water could become lodged in the tiny constrictions of the devices. This would cause the weigher to operate improperly. Also the electronic weighers had been tested thoroughly and used in the field for some years at the time Phil completed his fluidic design. FMC management felt no motivation to replace the tested electronic weighers with the

untried fluidic weighers which gave no promise of better performance or lower cost.

At this stage Phil felt that the "burden of proof" for the fluidic weigher rested with him. He wanted to improve his weigher so that it would perform better than the ones in use. His first step was to improve the circuit he had already designed. He was able to develop a circuit which used only five devices instead of twelve (see Appendix A for a circuit diagram and Appendix B for a photograph). The cost of this design was still not significantly cheaper than the electronic one, however.

Next, Phil directed his attention toward the design of the scale head itself. Previously, he had considered only the sensing and logic portions of the weigher, as he had wanted to use the existing hardware. At this point, however, he felt that he might be more successful if he started all over and perhaps developed some new concepts about the design of the scale head. There were two major sources of error in the scale head mechanism which Phil hoped to reduce. These error sources included errors caused by the transfer of the package onto the scale head and errors introduced by the conveyor belt. Often a can has a pump on its rim at the points where the side seam meets the top and bottom surfaces. If the surface over which the conveyor belt moves is even slighly misaligned ($\pm$ .001 inch) with the scale head, the can tends to stumble or jump. This makes the can appear heavier or lighter than it is. In order to minimize the effect of these transfer errors, scale head deflections of at least .012 - .015 inches are desirable. However, the farther the scale head deflects, the more the belt supports the package (see Fig. 7). This makes packages

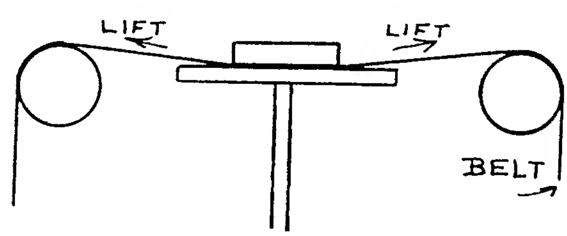


Figure 7. Lifting Effect of the Conveyor Belt

appear lighter than they are. Weighers can be calibrated to compensate for this circumstance. However, aging of the belt and other factors cause the amount of support to vary. This makes compensation for the lifting effect difficult.

Phil tried to carefully align the scale head with the input platform. This was not very successful, however, because the wear and tear of normal operation caused the system to go out of alignment. The scale head was very light so that its sensitivity would be good, but the fact that it was light made it easy to jolt out of alignment.

In order to improve performance, Phil designed a fluidic mechanism for pressing the scale head against a stop until a package was fully on the scale. Only then would the scale head be released and allowed to deflect. A "cat's whisker" attached to a flapper nozzle sensed the position of the can and determined when it was in weighing position. Phil hoped that this technique would reduce the errors caused by package transfer onto the scale head. In fact, his idea worked extremely well. Under ideal weighing conditions when the scale head and the input platform were precisely aligned and no stumbling occurred, weighing accuracy appeared to be slightly reduced. Under normal operating conditions, however, fifteen gram errors were reduced to errors of about two grams. Another advantage of Phil's new concept was that it permitted a package to move onto the scale head before the previous one was completely off. This was not possible without "lock-up" and provided a potential increase in weighing speed.

Another concept which Phil wanted to try was damped weighing. That is, he wanted to add a dash pot to the scale head and measure the steady state deflection of the scale. Previous designers had avoided damped weighing because they felt it would reduce sensitivity and increase weighing time. Damped weighing had the advantage of reducing the transfer error problem; it also reduced the effect of variations in belt tension. (Because much smaller deflections were used.) Damped

weighing also tends to reduce the effect of external vibration. Phil, however, had to increase the spring constant of the system in order to keep the weighing speed the same as before. Because of the increased spring constant and also the fact that static instead of dynamic deflection was being measured, sensitivity was reduced by about a factor of four. The increased spring constant also made the weigher more sensitive to drift in the pre-load adjustment.

Up to this time many of Phil's ideas for improvements on the fluidic weigher could have been used just as well on the electronic weigher. The fluidic lock-up mechanism was a notable exception. An electrical lock-up system which would be fast enough and develop enough force to be effective was not practical. While thinking about the sensitivity of the weigher to variations in spring pre-load in the damped weighing case, a new idea occurred to Phil. He thought of using a back pressure valve to sense the position of the scale head and to act as a spring in the system. This fluidic spring would not be sensitive to vibration and changes in temperature and would have quite constant characteristics. By choosing appropriate dimensions for the back pressure valve, the fluidic spring constant could be made large so that the spring constants of the mechanical springs in the system could be drastically reduced. Also, the back pressure valve would provide a direct input to the fluidic circuit. Pressure rather than scale head deflection would be the measure of the weight.

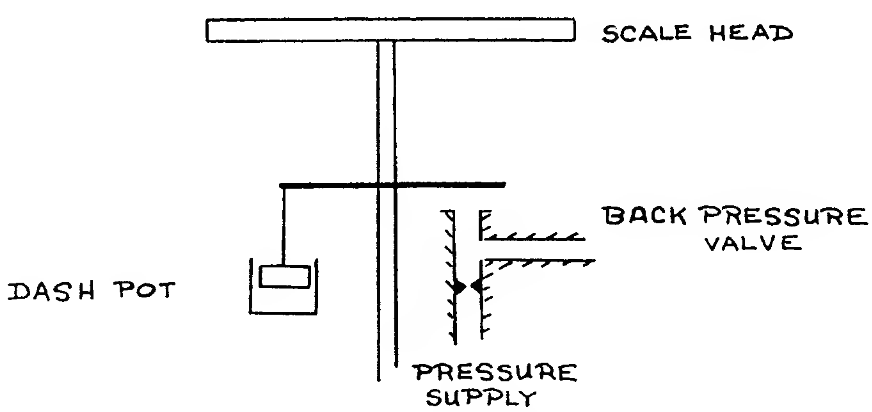


Figure 8. Damped Weighing Configuration with Dash Pot and Back Pressure Valve

Phil tested his new idea and it worked very well. He felt that the spring constants he had chosen were a little high so that high frequency noises such as cans rocking or chattering on the scale head affected the weigher. With a different spring constant, however, Phil thought that the weigher would perform better in this respect.

Phil thought of a way to improve the weigher still further by adding another flapper valve to the scale head mechanism to operate in a push-pull relation with the first. This scheme would improve performance but tended to be limited to applications in which only two categories of classification were required. There was a possibility that the idea could be extended for use with more than two categories, however.

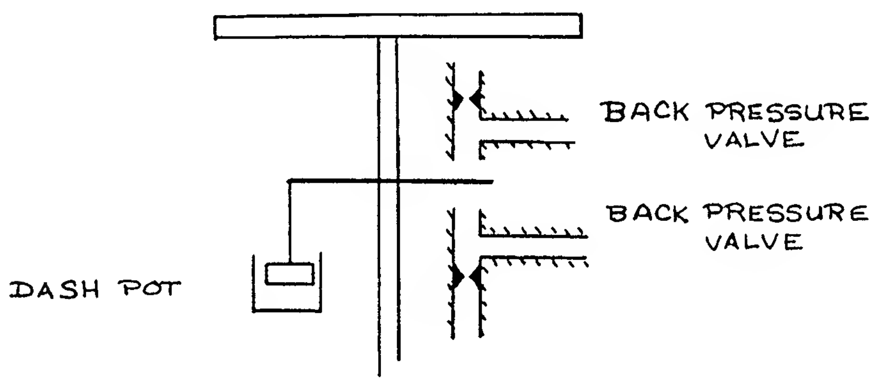


Figure 9. Use of Two Back Pressure Valves

At present FMC has built three fluidic weighers, which are being used for special applications such as weighing explosives. Phil now feels prepared to build a high speed, accurate weighing machine with excellent performance characteristics. FMC has continued to manufacture the electronic weigher because it has been proved in the field and furthermore, most applications do not require the performance that the fluidic weigher is capable of giving. FMC plans to sell the fluidic weigher for special applications. Exhibits 1 and 2 show the fluidic slide weigher and its fluidic circuitry.

APPENDIX

MTM-15

PNEUMATIC CONTROLS FOR SLIDE WEIGHER

Written by:

P. R. Bunnelle

P. R. Bunnelle
March 3, 1965

PNEUMATIC CONTROLS FOR SLIDE WEIGHER

Following the tests reported in MTM-14, work on the pneumatic operation of a Slide Weigher was continued by trying a different method of detecting scale deflection and by using a different type of fluid amplifier in the control circuit. Following is a description of this system.

Sensing

A flapper valve arrangement was used to detect scale deflection. As the scale deflected, a flapper attached to the scale head reduced the open area around the nozzle, causing pressure in the nozzle throat to build up. When there was sufficient scale deflection, this pressure caused a Corning bi-stable flip flop connected to the nozzle to change state. The point at which this switching occurred depended primarily on the geometry of the sensor, which also determined accuracy of detection. With the valve used in most of the tests, the actuating point was reproducible within about .0001 inch. Changes in supply pressure did not greatly affect switching point.

Circuit

A control circuit was breadboarded using Corning bi-stable fluid devices. These operate on the principle that a small control pressure in the proper pilot port will cause the power jet to switch from one outlet port to the other. In some devices (flip flops), the power jet remains stable after the pilot flow has ceased, thus providing memory. In others, internally biased, the power jet returns to the initial outlet as soon as the control flow ceases (or control pressure becomes sufficiently low). With parallel control inputs, this latter unit constitutes a logic OR/NOR element. The circuit used was made up of these two types of elements, five elements in all being used. The circuit is shown in the attached diagram. Logically, it is the same as that used with the turbulence amplifiers (as reported in MTM-14).

FF-1 senses pressure in the flapper nozzle, switches at the proper scale deflection and remains switched after the scale returns to its rest position. The output of this amplifier switches the output of NOR-1 to DUMP and causes FF-2 to switch. After the package leaves the scale head, it deflects a trip-operated flapper valve. The output of this trip provides one of the logic inputs to NOR-3 which is connected to the reject cylinder. If both the trip signal and the input from FF-2 are down (no memory of scale deflection), the output of NOR-3 switches, actuating the reject, which remains actuated as long as the trip pad is deflected. If FF-2 has memory of proper scale deflection, the reject is not actuated, but FF-1 is reset by the action of NOR-2 which serves to invert the signal from the trip pad. This same inverted signal also prevents the resetting of FF-2 by its action on NOR-1. When the trip pad is released, FF-2 is reset and the circuit is ready for the next cycle. The restriction

in the reset line of FF-1 serves to "improve" the memory of the element. It probably also provides a slight delay in the control signal so that NOR-1 actuates before FF-1 is reset.

This circuit was generally operated on 1-1/2 psi supply pressure. At this pressure the air usage per element was about .08 scfm. In a production circuit, all the logic elements and interconnections would be molded or etched in a single block.

Reject

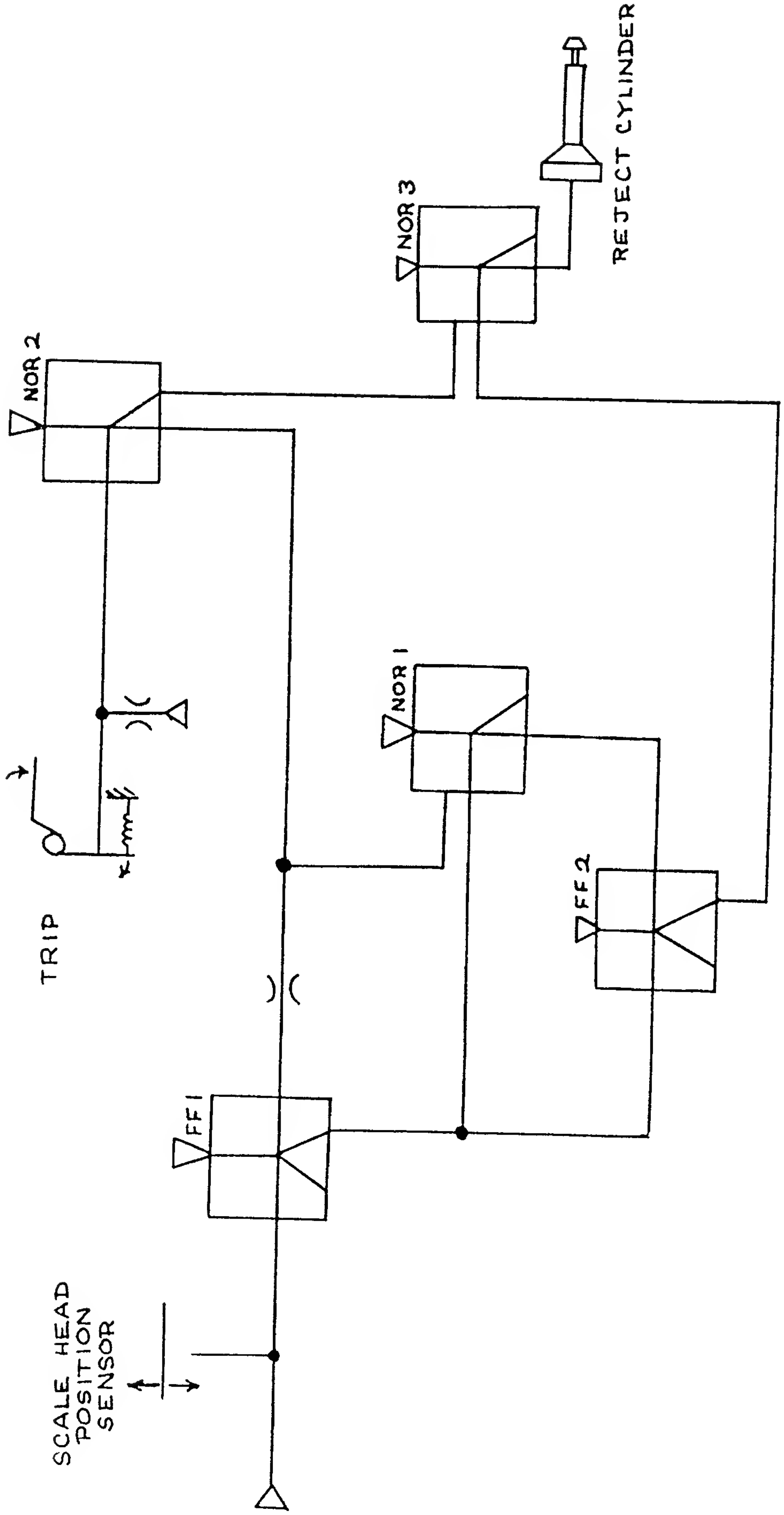
The same diaphragm-actuated reject cylinder used with the turbulence amplifier circuit was used with this system. This cylinder was adjustable laterally to accommodate different can sizes and axially for reject timing. (The trip could also be adjusted axially to accomplish the latter function.)

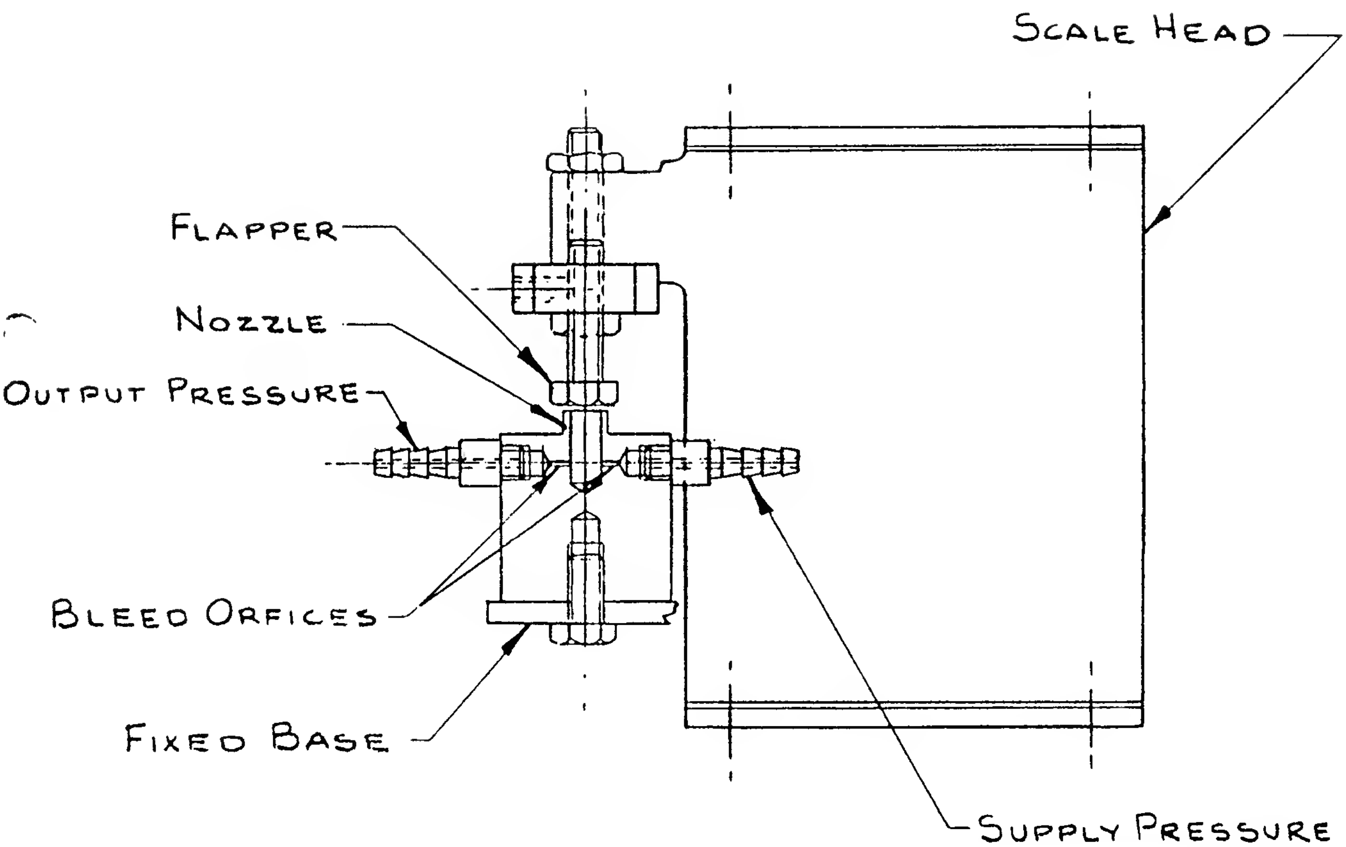
Performance

Overall accuracy of weighing with a Sefton carton was one to two grams. Using a round can the spread was considerably greater.

Conclusions

Based on limited tests the pneumatic control system described in this report appears to be suitable for Slide Weigher operation. However, it represents essentially a one for one substitution for the present electrical components and does not eliminate sources of weighing error caused by can transfer onto the scale head or the effects of external vibration. Further work is being undertaken in an attempt to reduce these sources of error by more fully exploiting the features of pneumatic detection and control.


REJECT CYLINDER
NOR 3
NOR 2
NOR 1
FF 2
FF1
TRIP
SCALE HEAD
POSITION
SENSOR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FLAPPER
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OUTPUT PRESSURE
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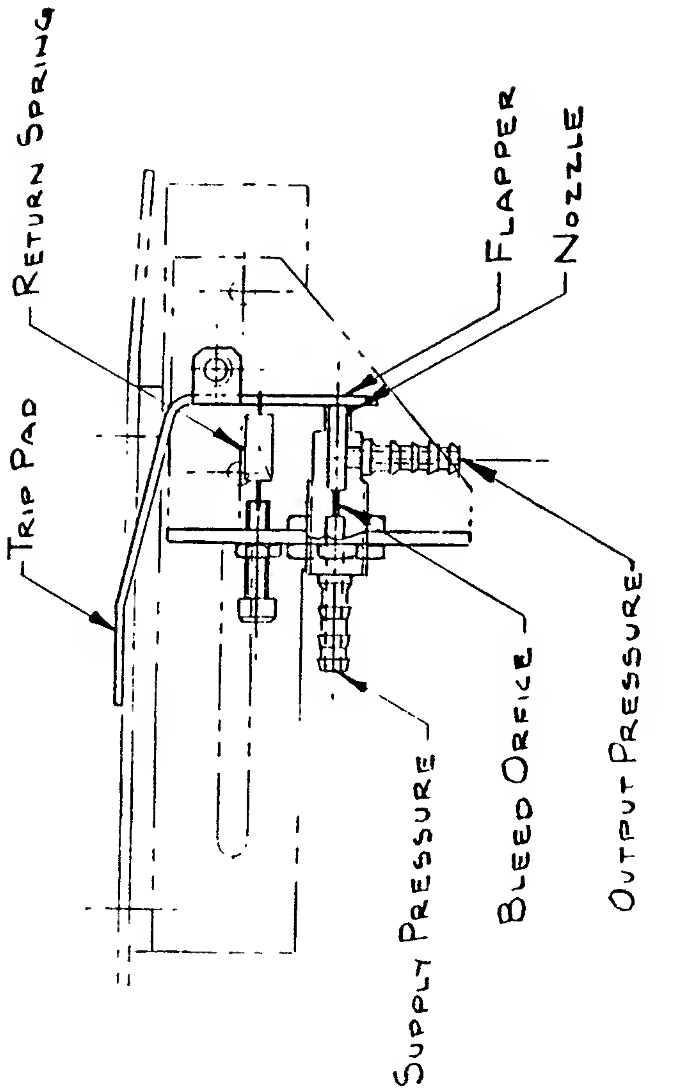
FIXED BASE
SUPPLY PRESSURE

SENSOR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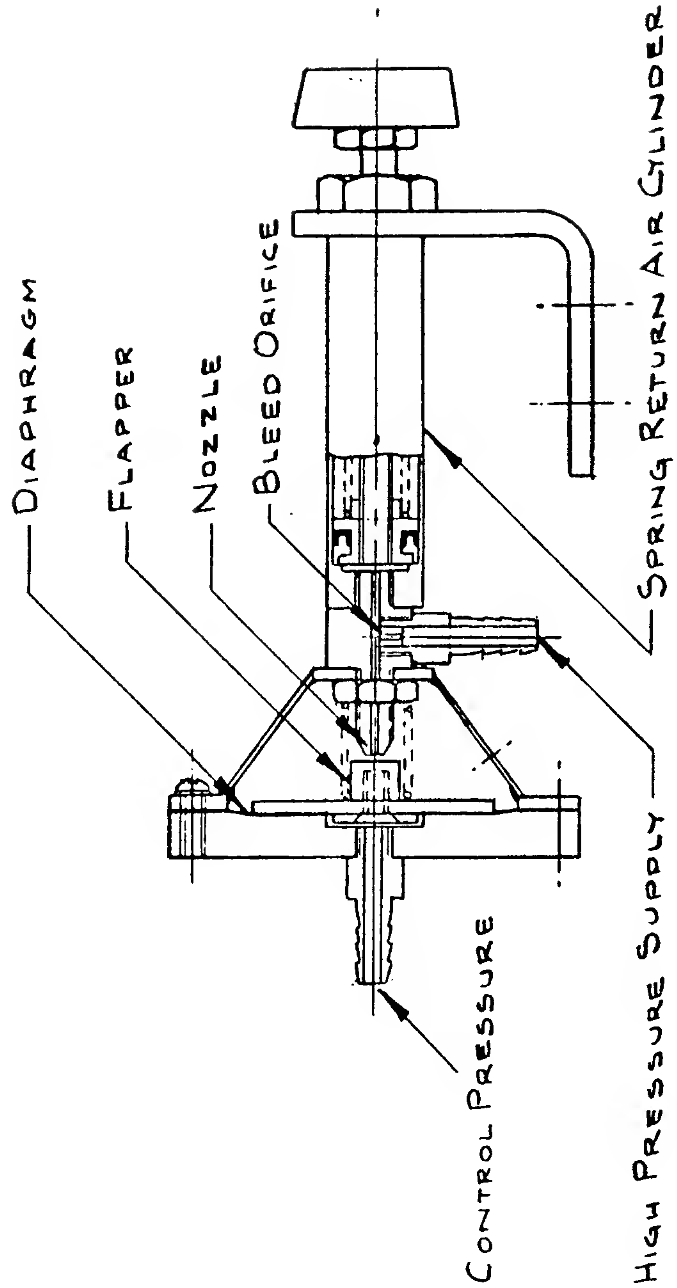
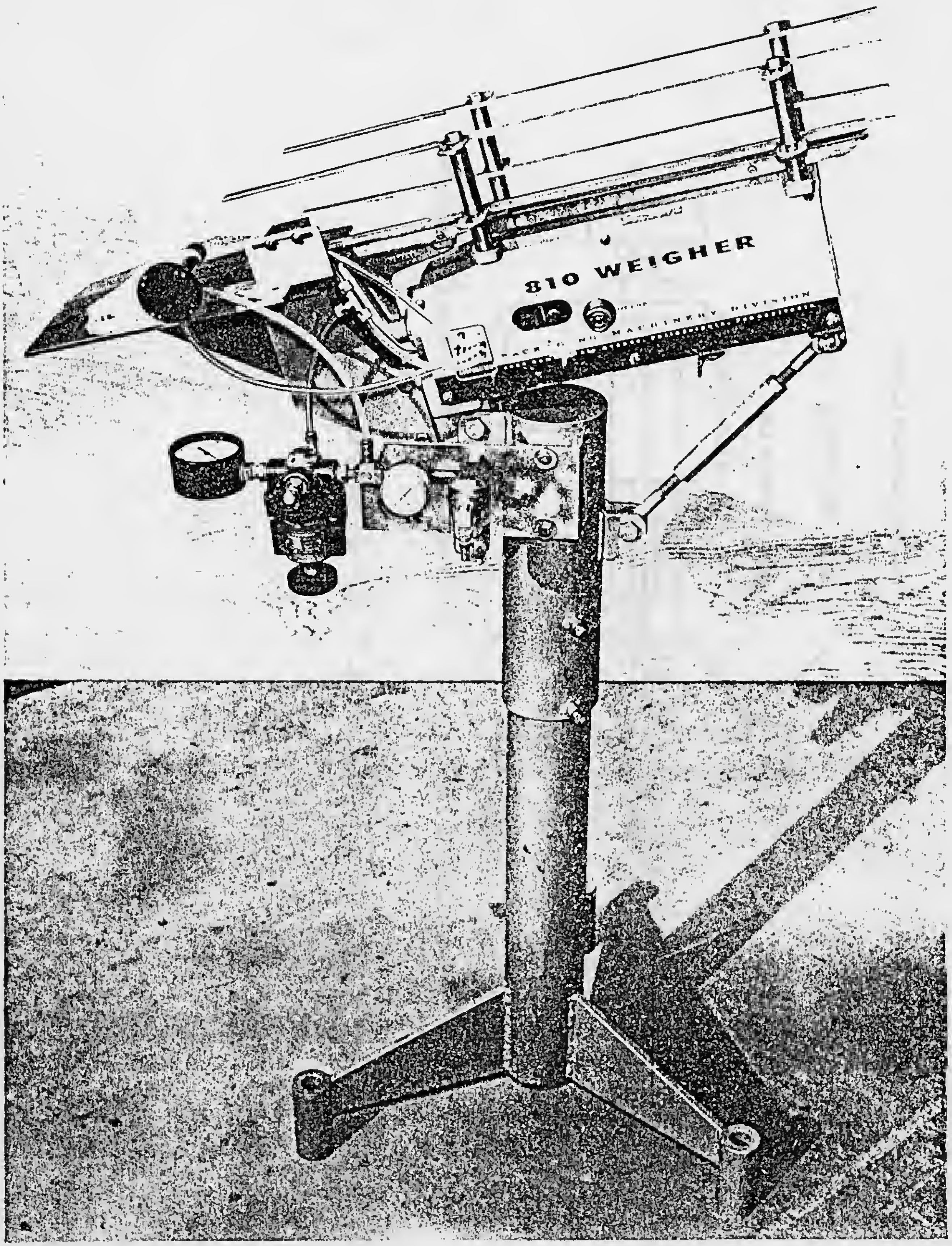
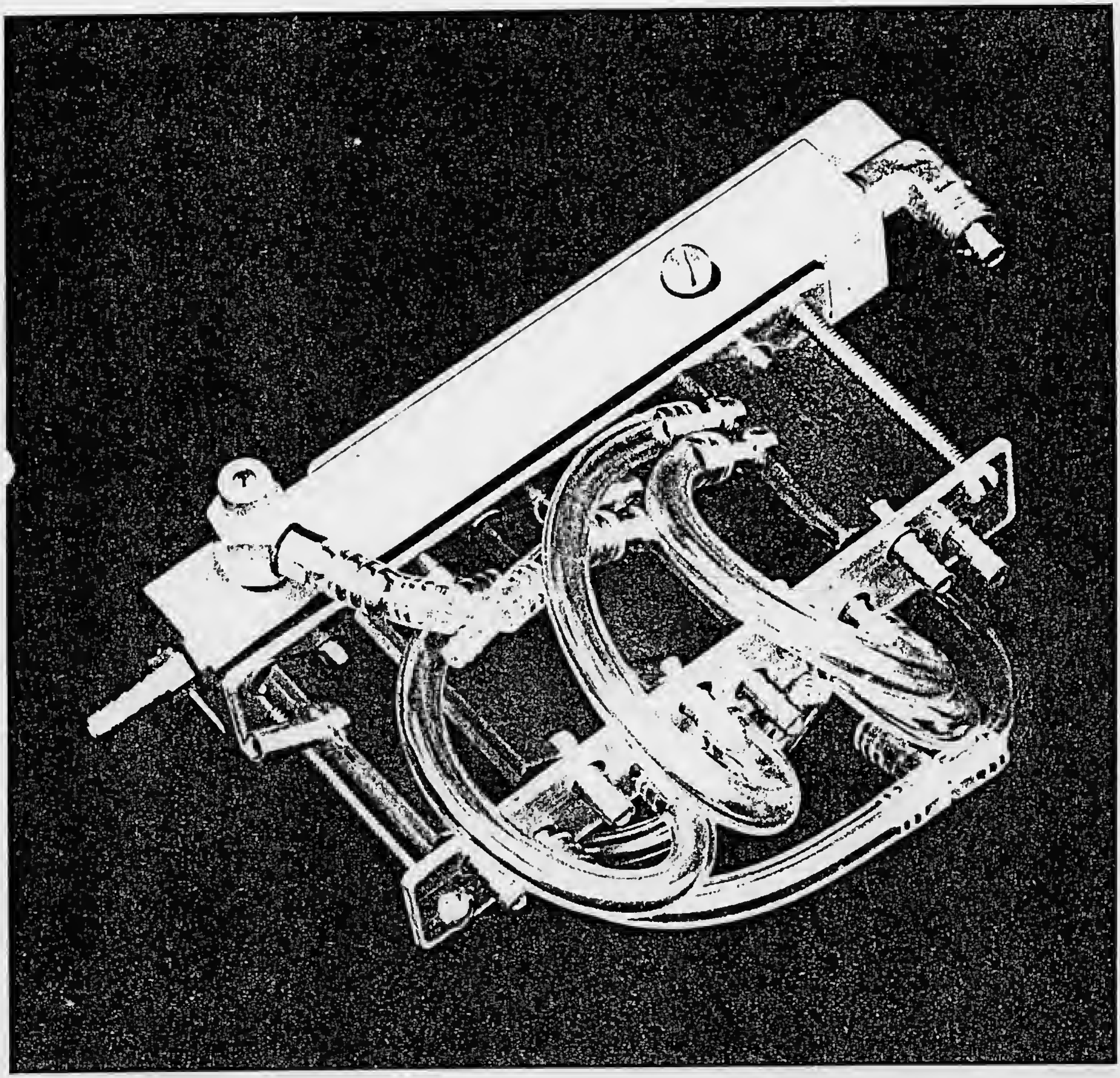


Reject Cylinder



Prototype Fluidic Slide Weigher

EXHIBIT I



Fluidic Circuitry of the Slide Weigher

EXHIBIT II